

Cell Structure, Reproduction and Development

revision notes

Cell Structure, Reproduction and Development is topic 3 of Pearson Edexcel International AS / A Level Biology (XBI11 / YBI11) and is examined in Unit 2. It covers the ultrastructure of eukaryotic and prokaryotic cells, microscopy, meiosis, fertilisation, mitosis and the cell cycle, and how stem cells, gene expression and epigenetics produce specialised cells and phenotypes.

For Pearson Edexcel International AS Biology XBI11 and International A Level Biology YBI11. **A Level only** is IA2 content (Units 4 to 6), not needed for the International AS.

1 Cells, tissues and organelles Spec 3.1-3.6

Features common to all living cells Spec 3.1

The **cell theory** says that all living organisms are made of cells and that the cell is the basic unit of life. Cells vary hugely in size and shape, but they share some common features.

- a **cell surface membrane** that controls what enters and leaves the cell
- **cytoplasm**, the gel-like fluid in which metabolic reactions take place
- **genetic material**, which is DNA, carrying the instructions for making proteins
- **ribosomes**, the sites of protein synthesis (translation)
- metabolic reactions, which are controlled by enzymes and use ATP as the energy currency

The two basic cell types		
Feature	Eukaryotic cell	Prokaryotic cell
DNA	Linear, in a nucleus with a nuclear envelope	Circular, free in the cytoplasm (not in a nucleus)
Membrane-bound organelles	Present (for example mitochondria, Golgi apparatus)	Absent
Ribosomes	Larger (80S)	Smaller (70S)
Examples	Animal, plant and fungal cells	Bacteria

Exam tip: A common-features question wants the feature and what it does. Write 'ribosomes, which make proteins', not just 'ribosomes'.

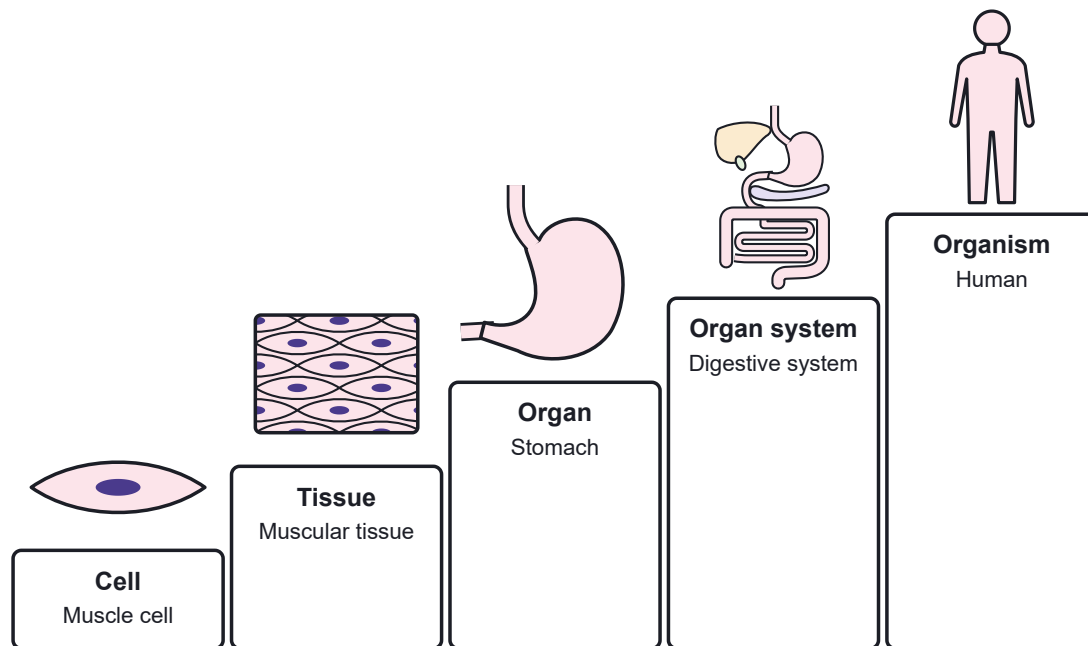
Tissues, organs and organ systems Spec 3.2

Cells in a multicellular organism are specialised for particular jobs. They are organised into levels of increasing complexity.

1. A **tissue** is a group of similar cells (with any extracellular material they make) that work together to perform a particular function, for example squamous epithelium, cardiac muscle or xylem.
2. An **organ** is a group of different tissues working together to perform a particular function, for example the stomach (epithelium, muscle, glandular and connective tissue) or a leaf.

3. An **organ system** is a group of organs working together to carry out a major body function, for example the digestive system (stomach, small intestine, pancreas, liver) or the circulatory system.

Specialisation means each cell type can be adapted to one task, and the tasks are coordinated, so the organism as a whole is more efficient than a collection of identical unspecialised cells. The same pattern of organisation applies to animals and to plants.



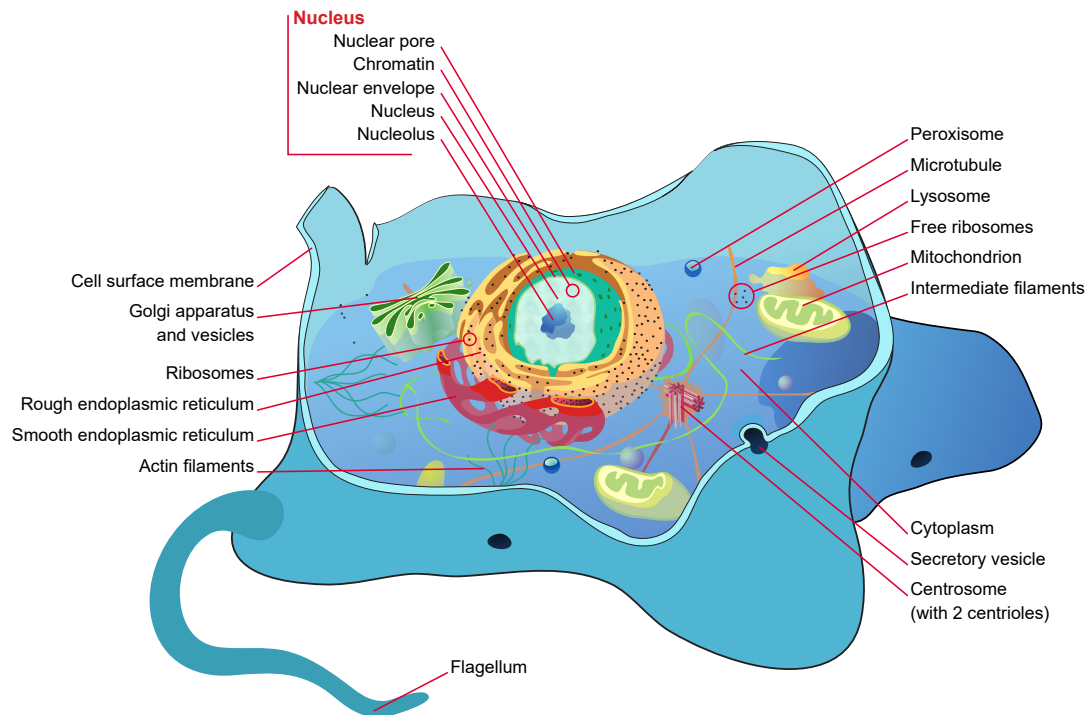
Cells form **tissues**, tissues form **organs**, and organs form **organ systems**.

Ultrastructure of eukaryotic cells Spec 3.3

Ultrastructure is the fine detail of a cell that can only be seen with an electron microscope. The organelles you need to know are summarised below.

Eukaryotic organelles: structure and function		
Organelle	Structure	Function
Nucleus	Surrounded by a double membrane (nuclear envelope) with nuclear pores; contains chromatin (DNA wound round histone proteins)	Stores genetic information; DNA is transcribed here; pores let mRNA out and proteins in; site of DNA replication
Nucleolus	Dense, darkly staining region inside the nucleus, with no membrane	Makes ribosomal RNA (rRNA) and assembles it with proteins into ribosome subunits
Ribosomes	Tiny, made of rRNA and protein, no membrane; free in the cytoplasm or attached to rough ER	Site of protein synthesis (translation)
Rough endoplasmic reticulum (rER)	System of flattened, membrane-bound sacs (cisternae) continuous with the nuclear envelope, with ribosomes on the outer surface	Proteins made on its ribosomes enter the lumen, where they are folded and transported
Smooth endoplasmic reticulum (sER)	Network of membrane-bound tubules with no ribosomes	Synthesises and transports lipids and steroids (for example steroid hormones)
Mitochondrion	Double membrane; inner membrane folded into cristae; fluid matrix inside	Site of aerobic respiration, producing ATP; cristae give a large surface area for the enzymes of the electron transport chain
Centrioles	A pair of short hollow cylinders at right angles to each other, each made of microtubules; found in animal cells	Form the spindle (organise the microtubules) during nuclear division
Lysosome	Small, round, single-membrane-bound sac, made by the Golgi apparatus, containing hydrolytic (digestive) enzymes	Digests worn-out organelles and material brought into the cell, such as bacteria engulfed by phagocytosis; can break down the cell itself after death
Golgi apparatus	A stack of flattened, membrane-bound sacs with vesicles budding from the edges	Modifies proteins (for example adds carbohydrate to make glycoproteins), packages them into vesicles, and makes lysosomes

Common mistake: Mitochondria do not 'make energy'. Say they produce ATP by aerobic respiration, which is the immediate source of energy for the cell.



Ultrastructure of a generalised animal cell. Only some animal cells have a flagellum.

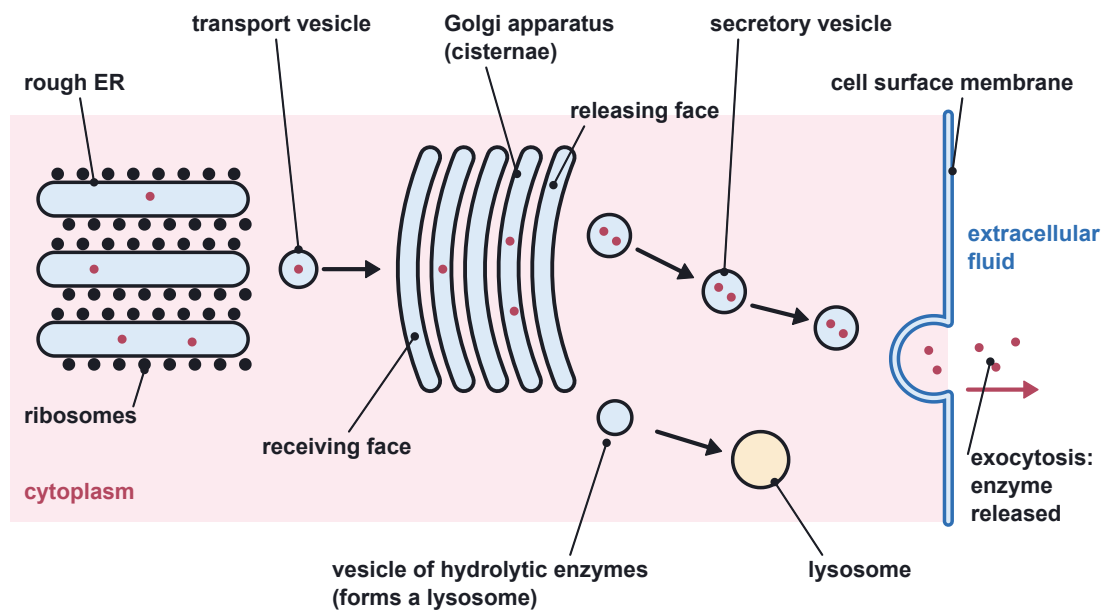
Image: Mariana Ruiz Villarreal (LadyofHats), Public domain, via Wikimedia Commons

Protein transport and extracellular enzymes Spec 3.4

Proteins that are to leave the cell, such as **extracellular enzymes** (digestive enzymes released by pancreatic cells are an example), follow a set route through the cell.

1. The gene is transcribed in the nucleus and the mRNA leaves through a nuclear pore.
2. The mRNA is translated by ribosomes on the **rough ER**. The new polypeptide passes into the lumen of the rER, where it is folded into its three-dimensional shape.
3. Small sections of rER bud off to form **transport vesicles**, carrying the protein to the Golgi apparatus.
4. The vesicles fuse with the Golgi apparatus. Here the protein is modified (for example carbohydrate is added to make a glycoprotein, or the protein is trimmed) and sorted.
5. The modified protein is packaged into **secretory vesicles** that pinch off from the Golgi apparatus.
6. Secretory vesicles move to the cell surface membrane (along the cytoskeleton), fuse with it and release the protein outside the cell by **exocytosis**.

The Golgi apparatus also packages hydrolytic enzymes into vesicles that remain in the cell as lysosomes. Cells that secrete a lot of protein, such as enzyme-secreting cells of the pancreas, have extensive rER and many Golgi stacks.



Route of a secreted protein: rough ER → transport vesicle → Golgi apparatus → secretory vesicle → exocytosis.

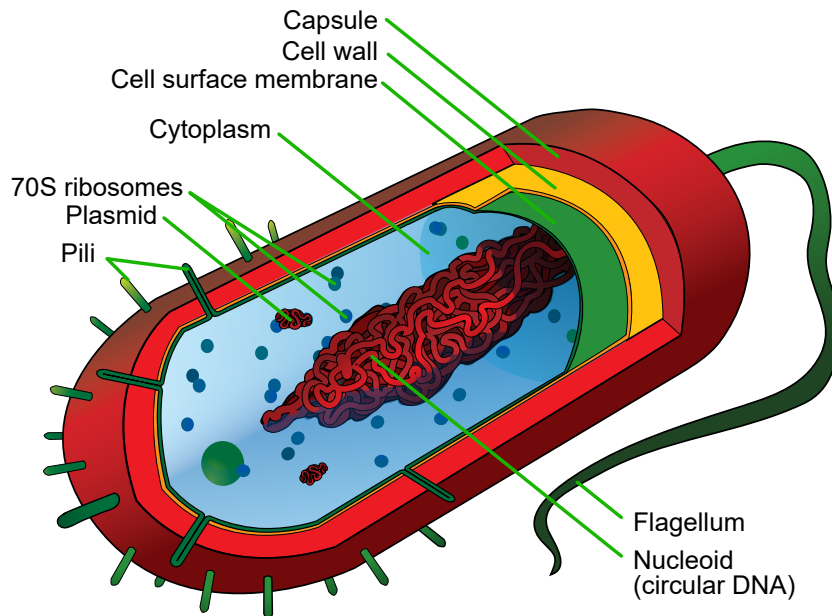
Exam tip: Give the route in the correct order (rER, transport vesicle, Golgi apparatus, secretory vesicle, cell surface membrane) and say what happens at each stage.

Ultrastructure of prokaryotic cells Spec 3.5

Prokaryotic cells (bacteria) are much smaller than eukaryotic cells and are structurally simpler. As well as a cell surface membrane and cytoplasm, you need to know these structures.

Structures in a prokaryotic cell		
Structure	Description	Function
Cell wall	Made of peptidoglycan (a polymer of sugars and amino acids)	Maintains the shape of the cell and prevents it bursting by osmosis
Capsule	Slimy layer of polysaccharide outside the cell wall (not all bacteria have one)	Protects the cell from drying out and from attack by the immune system, and helps cells stick to surfaces
Plasmid	Small loop of circular DNA, separate from the main DNA; may be many copies	Carries extra genes, for example for antibiotic resistance; can be passed to other bacteria
Flagellum	Long, thin, whip-like protein filament, rotated by a motor in the cell wall and membrane	Propels the cell (movement)
Pili	Short, thin protein hairs on the surface	Attach the cell to surfaces and to other cells; a special pilus allows DNA transfer between bacteria
Ribosomes	70S: smaller than eukaryotic 80S ribosomes	Protein synthesis
Circular DNA	A single, closed loop, not wound around histones, lying free in the cytoplasm in a region called the nucleoid	Carries the genes the cell needs

Common mistake: Prokaryotic DNA is not 'in a nucleus'. Say it is circular and lies free in the cytoplasm, with no nuclear envelope.



A prokaryotic cell: circular DNA free in the cytoplasm, **no nucleus** and no membrane-bound organelles.

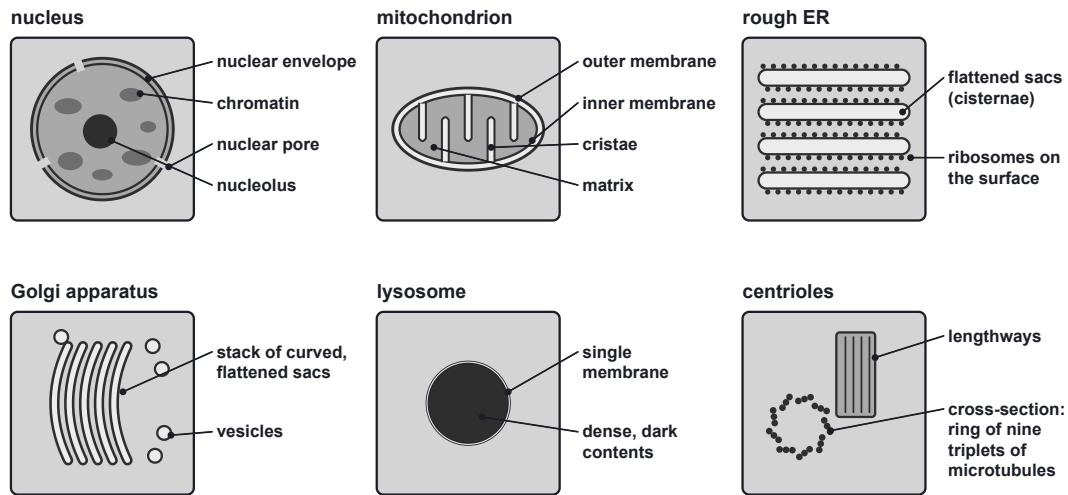
Image: Mariana Ruiz Villarreal (LadyofHats), Public domain, via Wikimedia Commons

Recognising organelles in electron micrographs Spec 3.6

Electron micrographs are black and white (any colour is added afterwards), and organelles are cut in section, so the shapes you see depend on how they were sliced. Look for these features.

How to recognise organelles in a transmission electron micrograph	
Organelle	What you see
Nucleus	Large, round or oval, with a double membrane broken by pores; dark patches of chromatin; a darker, denser nucleolus
Mitochondrion	Small oval or rod shape with a double membrane; the inner membrane folded into cristae, showing as lines or fingers inside
Rough ER	Parallel flattened sacs, often continuous with the nuclear envelope, with many tiny black dots (ribosomes) on the outer surface
Smooth ER	Branching tubules or sacs with no dots on the surface
Golgi apparatus	A stack of curved, flattened sacs, often with small vesicles near the ends
Lysosome	Small, round, single membrane, with dense, evenly dark contents
Ribosomes	Very small black dots, free or on rER
Centrioles	A pair of short cylinders at right angles: one is seen as a ring of microtubules in cross-section and the other lengthways

Exam tip: Describe what you see rather than guessing: 'double membrane with folded inner membrane' earns the mark for mitochondrion, and you can use it to identify the organelle.



Drawings of organelles as they appear in transmission electron micrographs (not to scale)

What to look for in a **transmission electron micrograph**.

Quick check

1. Name three features found in all living cells.
2. What is the function of the nucleolus?
3. Name the organelle that makes lysosomes.
4. How does prokaryotic DNA differ from eukaryotic DNA?
5. What are the features of a mitochondrion in an electron micrograph?

2 Microscopy and measuring cells Spec 3.7, 3.8

Magnification and resolution Spec 3.7

Magnification	How many times larger the image is than the real object.
Resolution	The smallest distance between two points at which they can still be seen as two separate points.

Magnification can be increased as much as you like, but the image only shows more detail if the **resolution** is good enough. Resolution is limited by the wavelength of the radiation used: two points closer together than about half the wavelength merge into one.

$$\text{magnification} = \text{size of image} \div \text{size of real object}$$

Light and electron microscopes compared			
Feature	Light microscope	Transmission electron microscope (TEM)	Scanning electron microscope (SEM)
Radiation	Light (wavelength about 400 to 700 nm), focused by glass lenses	Beam of electrons (very short wavelength), focused by electromagnets, in a vacuum	Beam of electrons scanned over the surface, in a vacuum
Maximum useful magnification	About $\times 1500$	Over $\times 1\,000\,000$	Up to about $\times 500\,000$
Resolution	About 200 nm (0.2 μm)	Roughly 0.1 to 0.5 nm	Roughly 3 to 10 nm
Specimen	Living or dead; thin section or whole mount	Dead, in a vacuum; extremely thin sections	Dead, in a vacuum; coated with a thin layer of metal
Image	Colour (if stained), 2D	Black and white, 2D, shows internal ultrastructure	Black and white, 3D appearance of the surface
Problems	Poor resolution; cannot see organelle detail	Preparation may create artefacts; cannot view living cells; expensive	Lower resolution than TEM; surface only

Electron microscopes have a much greater resolution than light microscopes because the **wavelength of electrons is much shorter** than the wavelength of light. This is why ribosomes, the Golgi apparatus and the inner membranes of mitochondria can only be seen with an electron microscope. Artefacts are structures that appear in the image because of the way the specimen was prepared and are not present in the living cell.

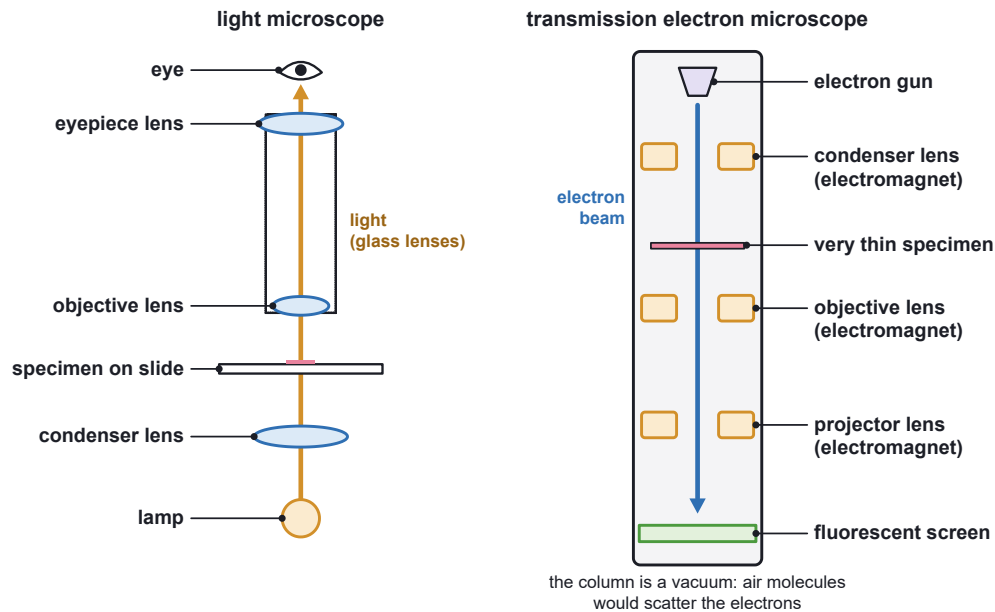
Calculating magnification

A drawing of a cell is 60 mm long. The actual length of the cell is 15 μm . Calculate the magnification of the drawing.

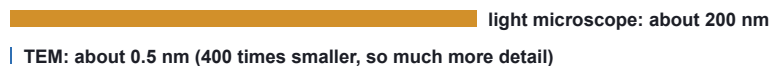
1. Convert both measurements to the same unit: 60 mm = 60 000 μm .
2. magnification = size of image $\div$ size of real object
3. magnification = 60 000 $\div$ 15

Answer: $\times 4000$

Maths skill: Write the formula, convert to the same units first, and give no unit for magnification (just x). To find the actual size, rearrange: $\text{actual size} = \text{image size} \div \text{magnification}$.



Resolution (same scale):



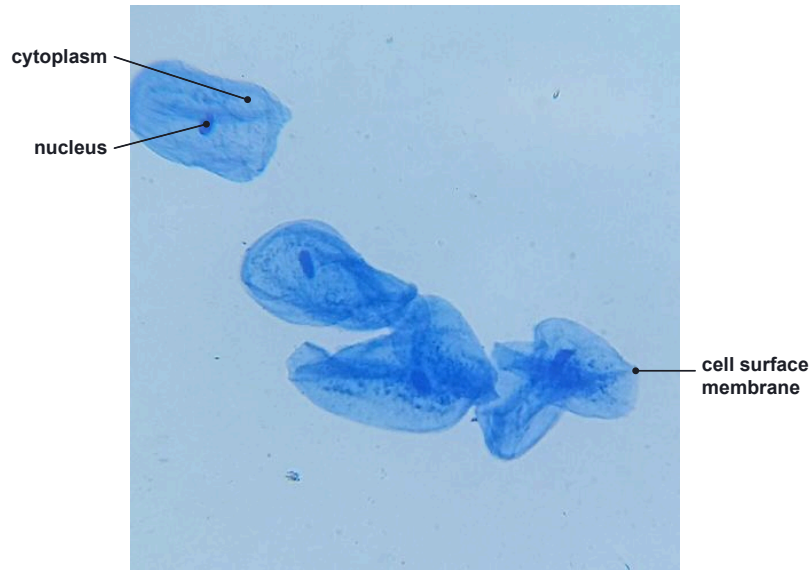
Electrons have a much shorter wavelength than light, so the TEM has a **much higher resolution**.

Staining specimens Spec 3.7

Cells are mostly water and are almost transparent, so structures inside them hardly absorb light and are difficult to see. **Staining** increases the contrast between structures, and different stains bind to different structures so they can be told apart.

- Light microscopy: coloured dyes absorb light and make structures visible. Examples are methylene blue (stains nuclei and cytoplasm blue), eosin (stains cytoplasm pink), iodine solution (stains starch blue-black) and acetic orcein or toluidine blue (stain DNA/chromosomes dark).
- Differential staining uses stains that bind to different structures, so that two tissues or two parts of a cell are different colours.
- Electron microscopy: the specimen is treated with salts of heavy metals, such as lead or uranium. These scatter electrons, so the stained parts look dark and the rest looks lighter. Different structures take up different amounts of metal, which gives the contrast that allows organelles to be identified.

Exam tip: The reason for staining is always contrast: structures are made visible and distinguishable. Say that, rather than 'to make it clearer'.



Cheek cells stained with **methylene blue**: the nucleus stains darker than the cytoplasm. Unstained, the cells are almost invisible.

Image: Fritzmann2002, CC BY-SA 4.0, via Wikimedia Commons

Core Practical 5: observing, drawing and measuring cells Spec 3.8

Core practical: Core practical 5: use a light microscope to make observations and labelled drawings of suitable animal cells, and use a graticule to make measurements and understand scale.

Preparing and viewing the slide

1. Wash hands. Use a clean cotton bud (or a sterile spatula) to gently scrape the inside of your own cheek.
2. Smear the cells onto a clean microscope slide in a drop of water or stain (for example methylene blue). Dispose of the swab in disinfectant.
3. Lower a coverslip at an angle with a mounted needle, to avoid trapping air bubbles. Blot excess stain with filter paper.
4. Start with the lowest-power objective lens, focus with the coarse focus and then the fine focus, and increase the magnification as needed.
5. Alternatively, use a prepared slide of an animal tissue, such as a section of liver or of squamous epithelium.

Making a labelled drawing

- Use a sharp pencil, a clear continuous line, no shading and no colouring.
- Draw only what you see. Make the drawing large (fill at least half of the space) and draw a few cells, not the whole field of view.
- Label with ruled lines that do not cross and touch the structure, and give the title, the magnification used and a scale bar.

Measuring with a graticule

An eyepiece **graticule** is a transparent scale with arbitrary divisions placed in the eyepiece. Its units have no fixed size, so it must be calibrated for each objective lens against a **stage micrometer**, a slide with a scale of known size (usually divisions of 10 μm).

1. Place the stage micrometer on the stage and focus on its scale.
2. Line up the zero of the graticule with the zero of the micrometer.

- Find a point further along where two divisions line up again. Count the graticule divisions and the micrometer divisions between these points.
- Calculate the size of one graticule division in μm .
- Replace the micrometer with the specimen and measure the cell in graticule divisions. Multiply by the calibration value. Repeat for several cells and calculate a mean.

Calibrating a graticule

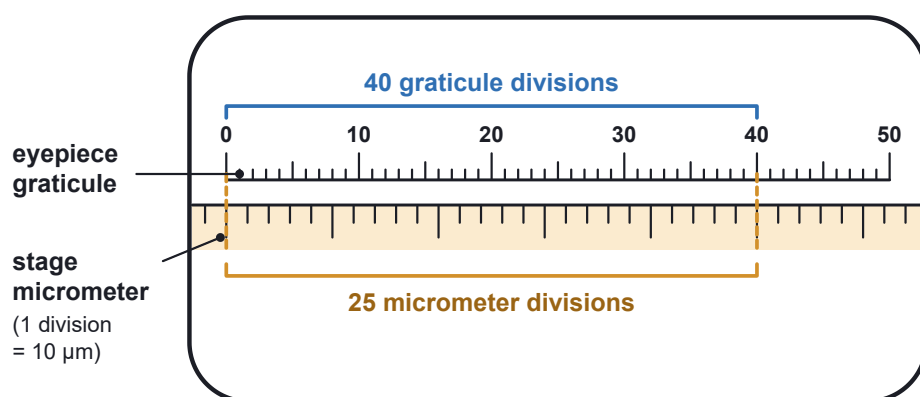
At $\times 400$, 40 graticule divisions are the same length as 25 divisions of a stage micrometer. Each micrometer division is $10\text{ }\mu\text{m}$. A cell measures 12 graticule divisions. Calculate the actual length of the cell.

- Length of 25 micrometer divisions = $25 \times 10 = 250\text{ }\mu\text{m}$
- One graticule division = $250 \div 40 = 6.25\text{ }\mu\text{m}$
- Cell length = 12×6.25

Answer: $75\text{ }\mu\text{m}$

Maths skill: Recalibrate whenever the objective lens is changed. Measuring several cells and finding the mean makes the result more reliable. Work in μm and convert to mm by dividing by 1000.

Risks and controls: your own cheek cells should not be shared and must be disposed of in disinfectant, to prevent the spread of infection. Stains such as methylene blue can stain skin and clothes. Take care with glass slides and coverslips, which can break. Wear eye protection if the stain is an irritant.



$$40 \text{ graticule divisions} = 25 \times 10\text{ }\mu\text{m} = 250\text{ }\mu\text{m}$$

$$1 \text{ graticule division} = 250\text{ }\mu\text{m} \div 40 = 6.25\text{ }\mu\text{m}$$

(calibration for this objective lens only)

Calibrating the graticule: 40 graticule divisions = $250\text{ }\mu\text{m}$, so 1 division = $6.25\text{ }\mu\text{m}$.

Quick check

- Define resolution.
- Why do electron microscopes have a higher resolution than light microscopes?
- Why are specimens stained?
- What is the formula for magnification?
- Why must an eyepiece graticule be calibrated?

3 Chromosomes, meiosis and gametes Spec 3.9–3.13

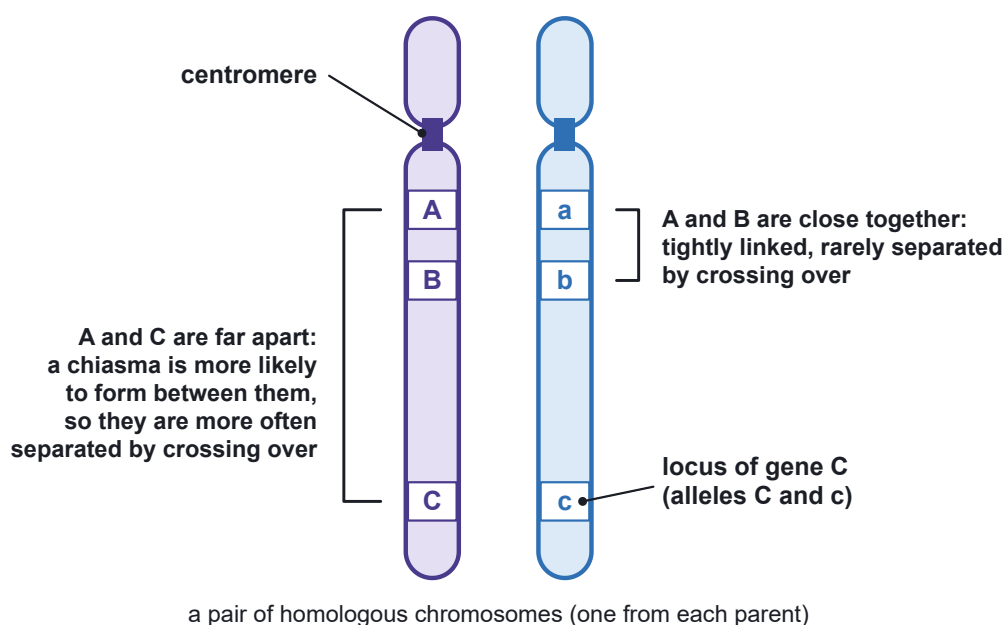
Gene loci and linkage Spec 3.9

Locus	The location of a gene on a chromosome. Plural: loci.
Linkage	Genes on the same chromosome are said to be linked, because they tend to be inherited together.

Body cells are diploid ($2n$): they contain pairs of **homologous chromosomes**, one from each parent. Homologous chromosomes carry the same genes at the same loci, but may carry different **alleles** (versions) of each gene.

Genes on different chromosomes are inherited independently, because the chromosomes assort independently at meiosis. Genes on the same chromosome are **linked**: the alleles on one chromosome are passed on together in the same gamete. This means a dihybrid cross involving linked genes does not give the expected 9:3:3:1 ratio.

Linked alleles can be separated by **crossing over** during meiosis, which produces new combinations of alleles called recombinants. The further apart two loci are on a chromosome, the more likely a chiasma forms between them, so the more often the linkage is broken. Loci that are very close together are rarely separated, so they are inherited together almost always.



Homologous chromosomes carry the **same genes at the same loci**; loci close together are rarely separated.

Exam tip: A locus is a position, not a gene and not an allele. Say 'the location of a gene on a chromosome'.

Meiosis and genetic variation Spec 3.10

Meiosis is the division that makes gametes. It involves two divisions, with only one round of DNA replication beforehand, so a diploid cell ($2n$) produces four **haploid** (n) cells. The cells are not identical to each other, which is a source of **genetic variation** in the offspring.

1. Meiosis I (reduction division): homologous chromosomes pair up. They are separated, so each daughter cell is haploid but each chromosome still has two chromatids.

2. Meiosis II: the chromatids of each chromosome are separated, as in mitosis. Four haploid cells result.

Crossing over in prophase I

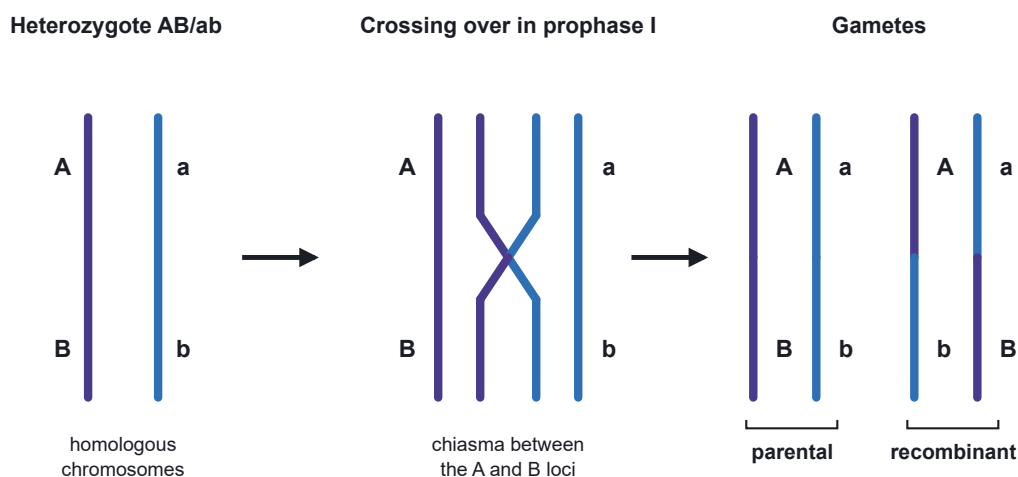
Homologous chromosomes pair up to form a **bivalent**. Chromatids of the two homologous chromosomes (non-sister chromatids) break and rejoin at points called **chiasmata**, exchanging sections of DNA. This swaps alleles between the chromatids, so each chromatid now carries a new combination of alleles. (The names of the stages of prophase are not required.)

Independent assortment in metaphase I

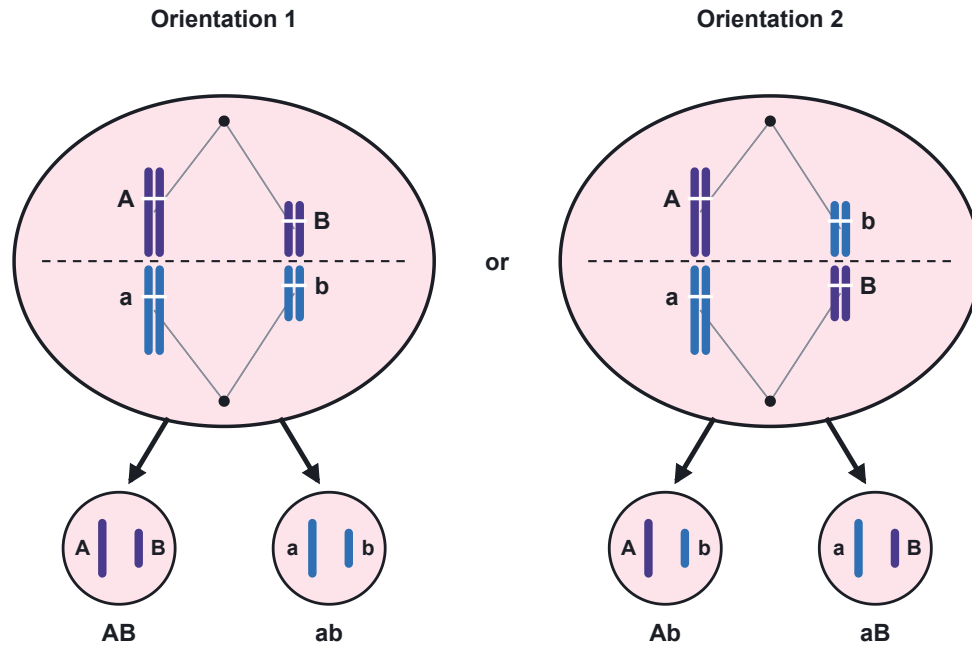
In metaphase I, the bivalents line up on the equator of the cell. Each pair lines up independently of the others, and the maternal or paternal chromosome of each pair can face either pole at random. When the homologous chromosomes separate in anaphase I, the cells receive a random mixture of maternal and paternal chromosomes. This is **independent assortment**.

number of possible chromosome combinations in gametes = 2^n (n = haploid number)

In humans $n = 23$, so independent assortment alone can produce $2^{23} = 8\,388\,608$ different combinations of chromosomes in the gametes of one person, before crossing over is taken into account. Crossing over adds more variation. Variation is also increased because fertilisation is random, so any sperm may fertilise any egg.



Crossing over at a chiasma produces new combinations of alleles (recombinants).



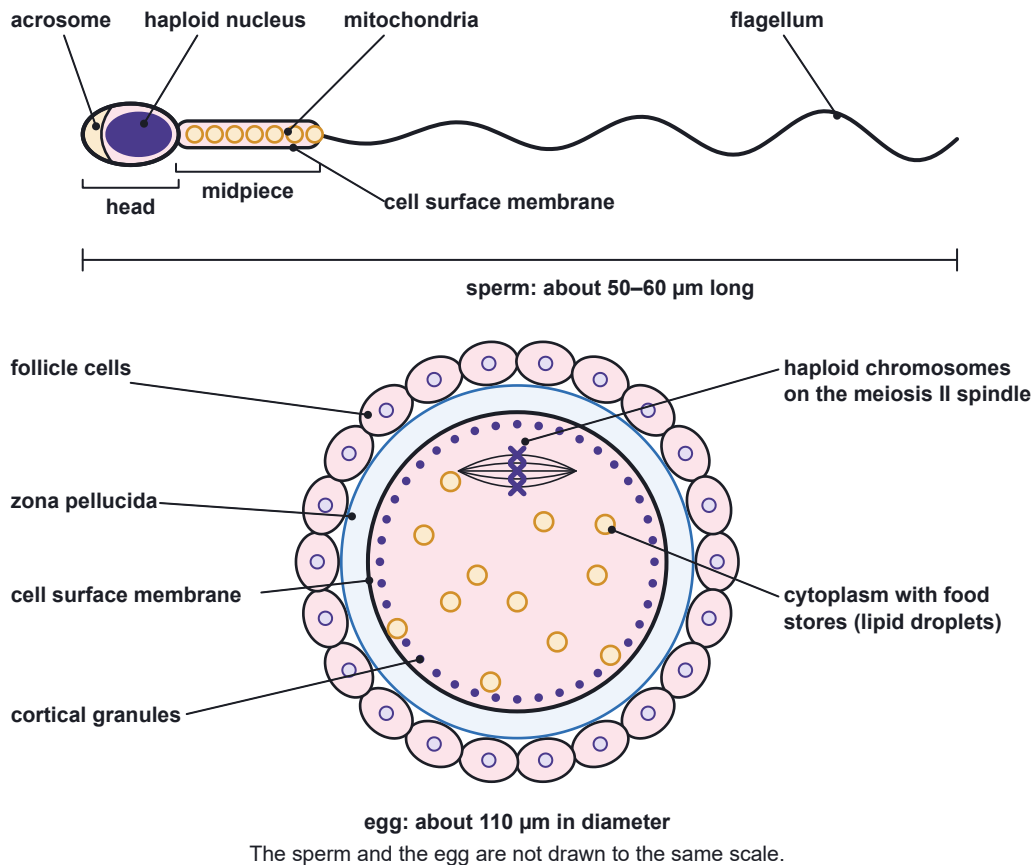
Independent assortment: each pair lines up independently, so two pairs give four kinds of gamete.

Common mistake: Crossing over is between non-sister chromatids of homologous chromosomes. Independent assortment is the random orientation of whole homologous pairs in metaphase I, not the separation of chromatids.

Specialised mammalian gametes Spec 3.11

Specialised features of mammalian gametes		
Gamete	Feature	Function
Sperm	Haploid nucleus in the head	Carries the paternal genes
Sperm	Acrosome at the front of the head: a modified lysosome containing hydrolytic (digestive) enzymes	Releases enzymes to digest a path through the zona pellucida
Sperm	Midpiece with many mitochondria, wound round the base of the flagellum	Produces ATP by aerobic respiration for swimming
Sperm	Long flagellum (tail) containing microtubules	Moves the sperm towards the egg
Egg cell	Large cell with a haploid nucleus and a lot of cytoplasm, containing food stores	Supplies nutrients to the early embryo until it implants
Egg cell	Zona pellucida: a jelly-like layer of glycoproteins outside the cell surface membrane	Contains receptors that bind sperm of the same species; protects the egg; hardens after fertilisation
Egg cell	Cortical granules: vesicles just under the cell surface membrane, containing enzymes	Released after fertilisation to prevent other sperm entering (cortical reaction)

The egg is surrounded by a layer of follicle cells, which the sperm must pass. Both gametes are **haploid**, so when the nuclei fuse, the diploid number is restored.

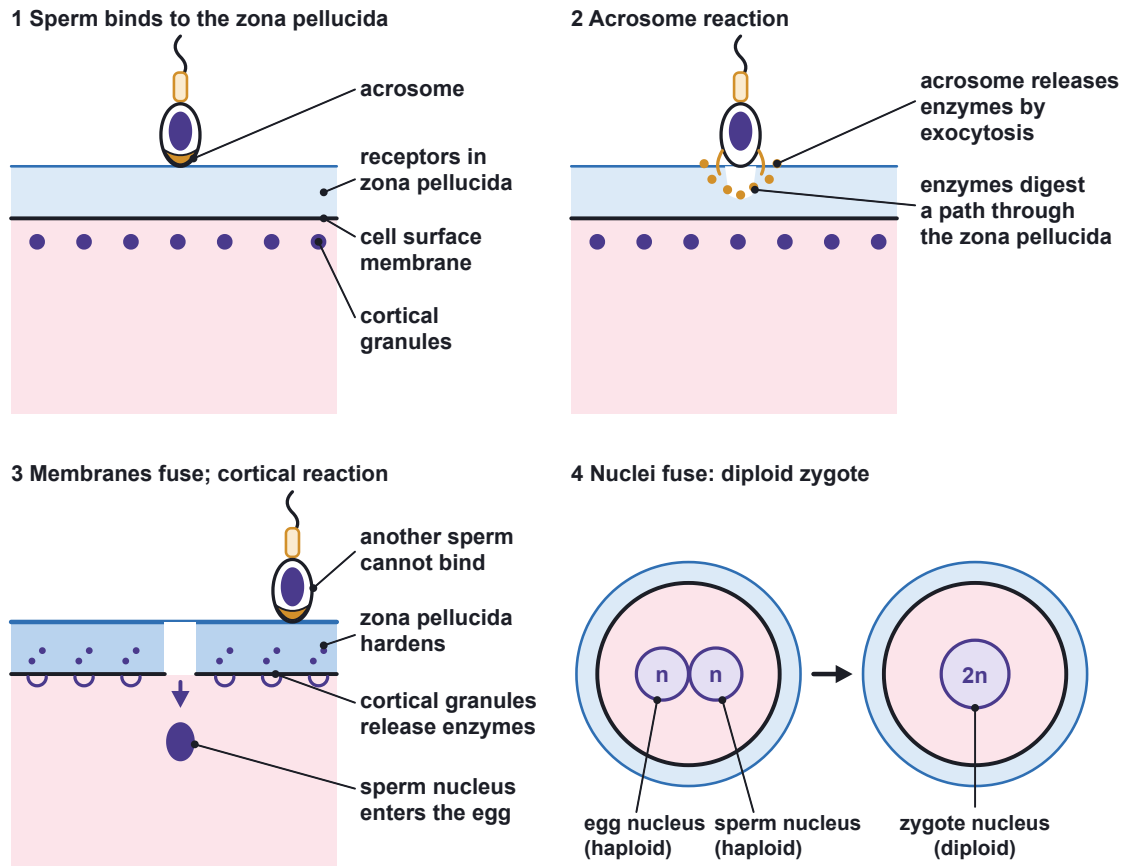


Mammalian gametes (not to the same scale): the egg is many times larger than the sperm.

Fertilisation in mammals Spec 3.12

1. Sperm swim towards the egg and pass through the layer of follicle cells.
2. The head of a sperm binds to receptors in the **zona pellucida**.
3. The **acrosome reaction** takes place: the acrosome membrane fuses with the sperm cell surface membrane and releases its enzymes by exocytosis. The enzymes digest a path through the zona pellucida.
4. The sperm cell surface membrane fuses with the egg cell surface membrane, and the sperm nucleus enters the egg cytoplasm.
5. The **cortical reaction** takes place: the cortical granules fuse with the egg cell surface membrane and release their enzymes. These change the zona pellucida so that it hardens and sperm can no longer bind to it.
6. The haploid sperm nucleus and haploid egg nucleus fuse, which forms a diploid zygote. This **fusion of nuclei** restores the diploid number.

The cortical reaction prevents **polyspermy** (more than one sperm fertilising the egg). If a second sperm entered, the zygote would have three sets of chromosomes and could not develop normally.



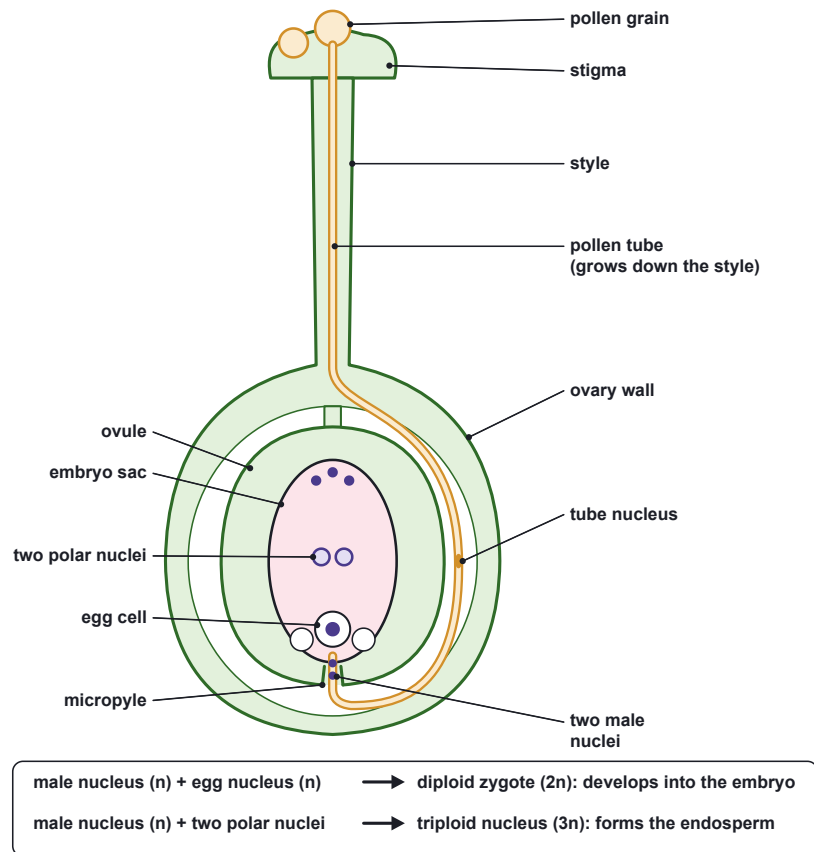
The **acrosome reaction** lets the sperm reach the egg; the **cortical reaction** stops other sperm entering.

Exam tip: Link each reaction to its purpose: the acrosome reaction lets the sperm reach the egg membrane, and the cortical reaction stops further sperm entering.

Fertilisation in flowering plants Spec 3.13

After pollination (the transfer of pollen to a stigma), the events of fertilisation take place in the following order.

1. A compatible pollen grain absorbs water and nutrients from the stigma and germinates.
2. A **pollen tube** grows out of the grain, down through the style towards the ovary. It is guided by chemicals released by the ovule (chemotropism), and the tube nucleus directs its growth. The tip of the tube secretes enzymes that digest the tissues of the style.
3. The generative nucleus divides by mitosis to form **two male nuclei**, which travel down the tube.
4. The tube enters the ovule through a small pore, the **micropyle**, and enters the embryo sac.
5. The tip of the tube bursts and releases the two male nuclei.
6. One male nucleus fuses with the nucleus of the egg cell to form a diploid zygote, which develops into the embryo.
7. The other male nucleus fuses with the two polar nuclei in the centre of the embryo sac to form a triploid nucleus, which develops into the endosperm (food store). This is called **double fertilisation**.



Double fertilisation: one male nucleus forms the zygote, the other forms the triploid endosperm nucleus.

Common mistake: The pollen tube carries nuclei, not sperm cells. Describe the fusion of nuclei: male nucleus with egg nucleus, and male nucleus with the polar nuclei.

Quick check

1. Define the term locus.
2. In which stage of meiosis does crossing over occur?
3. Why is the zona pellucida hardened after fertilisation?
4. What do the two male nuclei do in a flowering plant?
5. Why does a sperm have many mitochondria?

4 Mitosis and the cell cycle Spec 3.14–3.16

The cell cycle and mitosis Spec 3.14

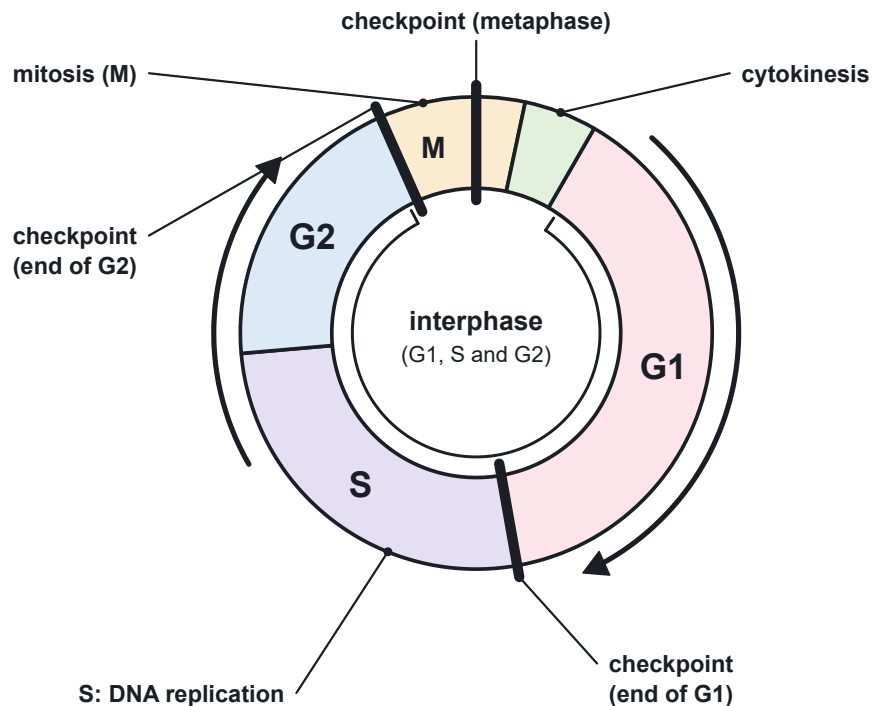
The **cell cycle** is the regular sequence of events in a dividing cell. It has two main parts: **interphase** (when the cell grows and DNA is replicated) and **mitosis** (nuclear division), followed by cytokinesis (division of the cytoplasm).

- G1: the cell grows and makes proteins and organelles.
- S phase: DNA is replicated, so each chromosome now consists of two identical sister chromatids joined at a centromere.
- G2: the cell continues to grow and prepares for division (for example by making the proteins for the spindle).

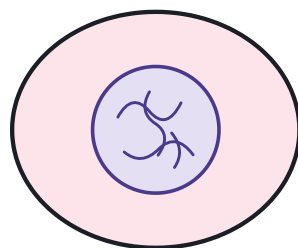
Stages of mitosis	
Stage	What happens
Prophase	Chromosomes condense and become visible as two sister chromatids joined by a centromere; the nuclear envelope breaks down; the nucleolus disappears; the spindle forms (in animal cells the centrioles move to opposite poles and organise it; plant cells have no centrioles)
Metaphase	Chromosomes line up on the equator of the cell, attached to spindle fibres by their centromeres
Anaphase	Centromeres divide; spindle fibres shorten and pull the sister chromatids (now chromosomes) to opposite poles
Telophase	Chromosomes arrive at the poles and uncoil; nuclear envelopes re-form; the nucleolus re-forms; the spindle breaks down
Cytokinesis	The cytoplasm divides, forming two daughter cells (not part of mitosis itself)

Because DNA is replicated exactly and each daughter cell receives one copy of every chromosome, mitosis produces two **genetically identical** daughter cells, with the same number of chromosomes as the parent cell. The role of mitosis in organisms includes:

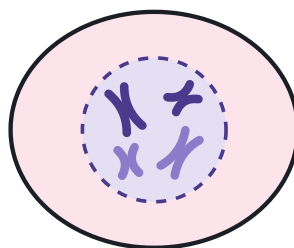
- growth of multicellular organisms, by increasing the number of cells
- replacement of damaged or worn-out cells and repair of tissues
- asexual reproduction, in which offspring are genetically identical clones of the parent, such as budding in yeast or the growth of runners and bulbs in plants



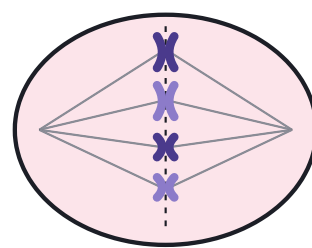
The cell cycle: **interphase** (G1, S, G2) takes most of the time, then mitosis and cytokinesis.



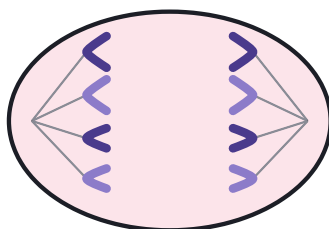
1 Interphase
cell grows; DNA replicated



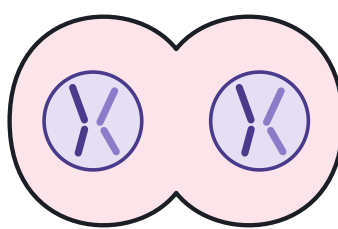
2 Prophase
chromosomes visible;
nuclear envelope breaks down



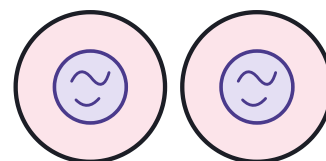
3 Metaphase
chromosomes line up on the
equator; spindle fibres attach
to the centromeres



4 Anaphase
sister chromatids pulled
to opposite poles



5 Telophase
nuclear envelopes re-form:
two nuclei



6 Cytokinesis
cytoplasm divides:
two daughter cells

Stages of mitosis: **prophase, metaphase, anaphase, telophase**, then cytokinesis.

Exam tip: In anaphase, say that the sister chromatids are pulled apart, and that the centromeres divide. Do not say that 'chromosomes' are pulled apart without saying they are chromatids at that moment.

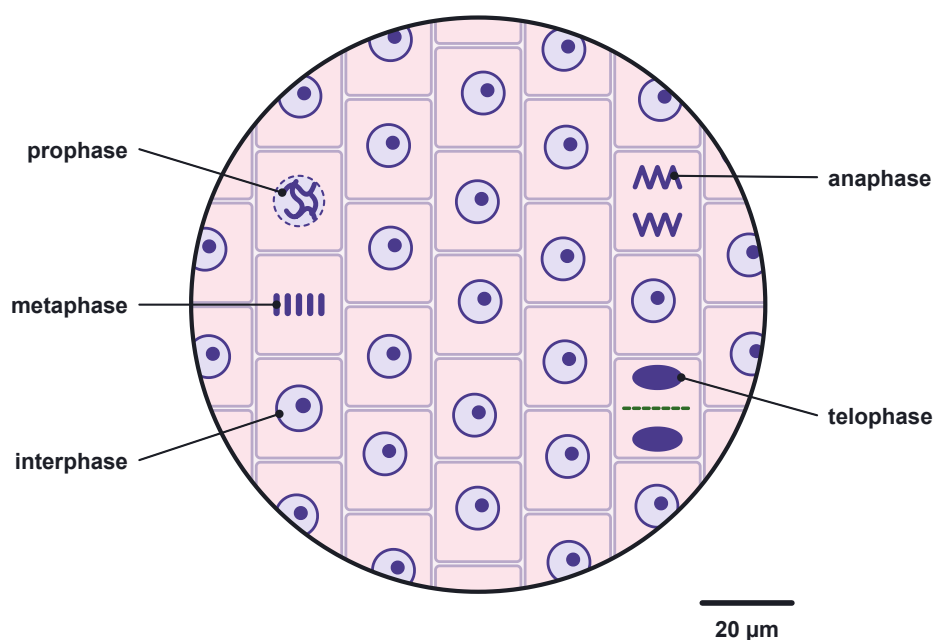
Core Practical 6: root tip squash Spec 3.15

Core practical: Core practical 6: prepare and stain a root tip squash to observe the stages of mitosis.

Root tips (for example onion, garlic or broad bean) are used because the meristem just behind the tip is the region where cells are dividing rapidly by mitosis.

1. Cut about 2 to 3 mm from the end of a growing root tip with a scalpel and place it in warm (about 60 °C) 1 M hydrochloric acid for about 5 minutes. The acid softens the tissue by breaking down the middle lamella between cells, so that the cells can be separated, and it kills the cells, fixing them in their stage.
 2. Rinse the root tip in water and place it on a clean microscope slide.
 3. Add a few drops of a stain that binds to chromosomes, such as acetic orcein, and leave for a few minutes. Spread out the tissue with a mounted needle.
 4. Lower a coverslip on at an angle. Cover it with a piece of filter paper and press down firmly with a thumb, without sliding the coverslip sideways, to squash the tissue into a thin layer of cells.
 5. View under a light microscope, starting at low power to find the region with small, square, densely stained cells, then at high power to identify the stage of each cell.
 6. Make labelled drawings of cells in each stage and count the cells in each stage in several fields of view.
- Variables to control when comparing roots: same type of plant, same length of root tip, same time in acid and stain, same temperature.
 - Risks: 1 M hydrochloric acid is an irritant, so wear eye protection; hot water baths can scald; acetic orcein stains skin and clothing and is an irritant; scalpels are sharp, so cut away from the body on a hard surface.
 - Reliability: count a large number of cells (at least several hundred) and repeat on several root tips to reduce the effects of chance.

Exam tip: Explain each step, not just the order. The squash gives a layer one cell thick, so light can pass through, and the acid separates the cells and stops further division.



In a root tip squash most cells are in interphase, because it is the longest part of the cell cycle.

Calculating the mitotic index Spec 3.16

$$\text{mitotic index} = \text{number of cells in mitosis} \div \text{total number of cells observed}$$

The mitotic index can be given as a decimal, a fraction or a percentage (multiply by 100). To find it in a root tip squash, count the cells in any stage of mitosis (prophase to telophase, where chromosomes can be seen) and the total number of cells in the same field or fields of view. Cells in interphase count only in the total.

Calculating a mitotic index

In a root tip squash, a student counted 250 cells in several fields of view. 40 of these cells were in mitosis. Calculate the mitotic index as a percentage.

1. mitotic index = number of cells in mitosis $\div$ total number of cells
2. mitotic index = $40 \div 250 = 0.16$
3. As a percentage = 0.16×100

Answer: 16%

A tissue with a high mitotic index is growing or repairing itself, as in a root meristem. Comparing the mitotic index of different regions, or of tissues treated differently, shows where division is fastest. Counting a large number of cells in many fields of view makes the value more reliable.

Maths skill: Give a percentage if the question asks for it, and check that your count of cells in mitosis is not greater than the total.

Quick check

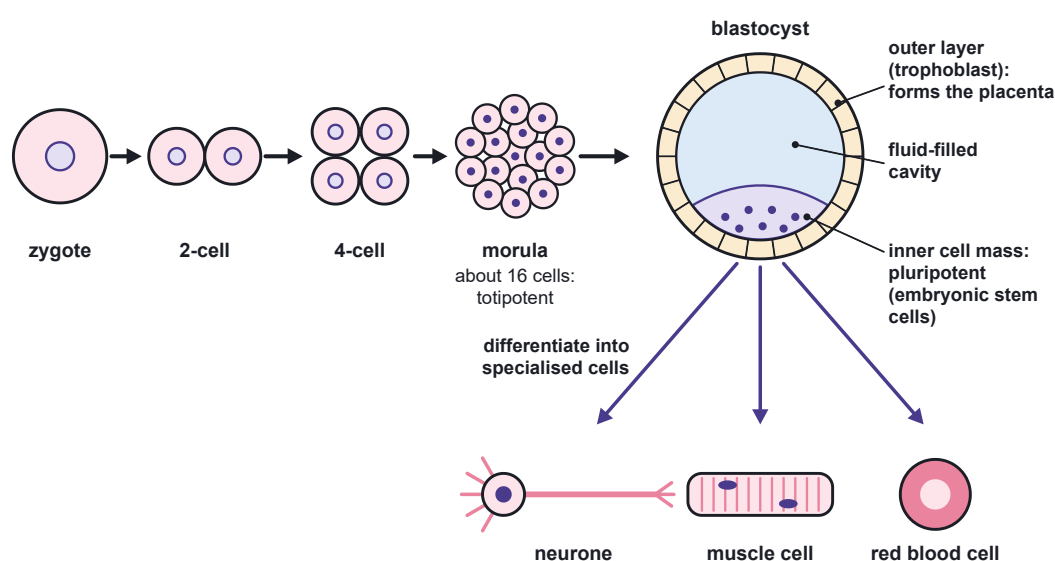
1. In which phase of the cell cycle is DNA replicated?
2. What happens to the chromosomes in metaphase?
3. Why are daughter cells from mitosis genetically identical?
4. Why is the root tip used for studying mitosis?
5. How is the mitotic index calculated?

5 Stem cells, gene expression and phenotype Spec 3.17-3.21

Stem cells and potency Spec 3.17

Stem cell	An undifferentiated cell that can divide by mitosis to produce more stem cells and can differentiate into specialised cell types.
Totipotent	Able to differentiate into any type of cell, including the cells of the extra-embryonic tissues such as the placenta, so can form a complete organism.
Pluripotent	Able to differentiate into almost any type of cell in the body, but not extra-embryonic tissues, so cannot form a complete organism.
Morula	A solid ball of about 16 cells formed by early cell divisions (cleavage) of the zygote.
Blastocyst	A hollow ball of cells with a fluid-filled cavity, an outer layer of cells that forms the placenta, and an inner cell mass of pluripotent cells.

After fertilisation, the zygote divides repeatedly by mitosis, without growing, to form a **morula**. Its cells are **totipotent** at first. Further divisions produce a **blastocyst**: the outer layer (the trophoblast) forms the placenta and the inner cell mass becomes the embryo. The cells of the inner cell mass are **pluripotent**. They are known as embryonic stem cells and can be collected and grown in a culture to make specialised cells.



Morula cells are **totipotent**; cells of the inner cell mass are **pluripotent**.

Exam tip: The difference to remember: totipotent cells can form any cell including the placenta (the whole organism); pluripotent cells can form any body cell but not the placenta.

Using stem cells in medical therapies Spec 3.17

Stem cells could be used to treat conditions in which cells are lost or damaged, such as some forms of blindness, spinal injury, Parkinson's disease and type 1 diabetes. Cells would be grown in culture, directed to differentiate, and transplanted into the patient. Bone marrow transplants, which use adult stem cells from bone marrow, are already used to treat some blood disorders. Adult stem cells avoid destroying an embryo, but they can form only a limited range of cell types.

Arguments about using embryonic stem cells

For	Against
They could treat serious diseases and injuries that currently cannot be cured	Collecting embryonic stem cells destroys the embryo, which some people believe is a human life with the right to life
Spare embryos from IVF treatment would otherwise be destroyed	Some religious and moral views oppose any use of embryos; some people fear that it could lead to the creation of embryos for research
Stem cells divide indefinitely in culture, giving a large supply of cells	Risk of tumours if the cells divide uncontrollably after transplant, and of rejection or infection
Research gives scientific understanding of development and genetic disease	Treatments are expensive, and the benefits are still uncertain

Scientists provide evidence about what is possible and the risks involved, but they cannot decide whether the research should be done. Society makes the decision. Governments set laws and set up regulatory bodies that license and monitor research (for example, strict limits on how long embryos may be kept). Ethics committees, religious and patient groups, the media and the public all contribute opinions. Decisions can differ between countries and change as the science develops.

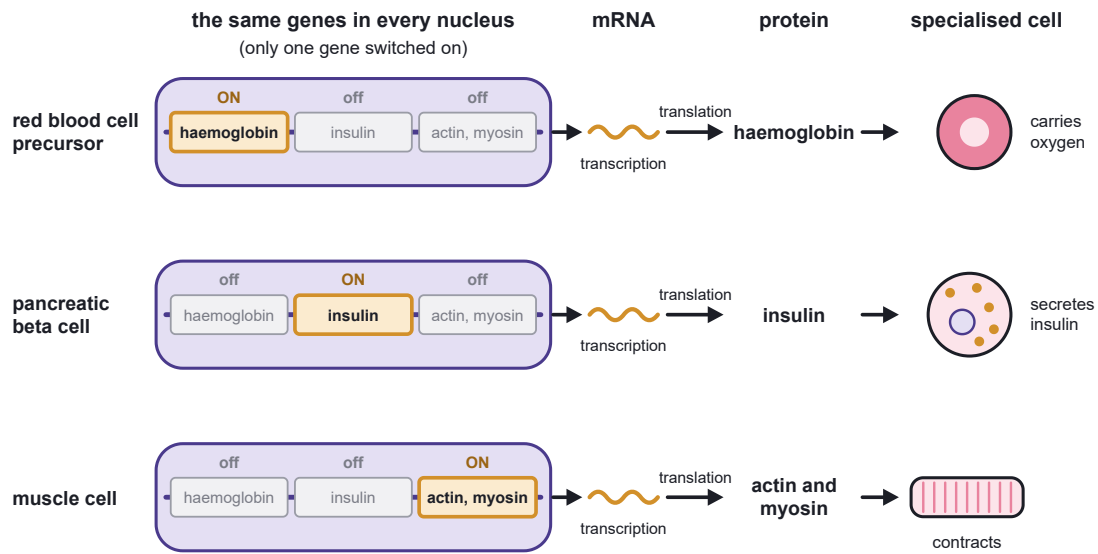
Exam tip: In a 'discuss' answer, give arguments on both sides (benefits and objections), and say who decides: laws and regulation, based on scientific evidence and public opinion.

Differential gene expression and specialisation Spec 3.18

Every body cell of an organism is produced by mitosis from the zygote, so each contains the same genome. Cells differ because of **differential gene expression**: in each type of cell, only particular genes are switched on and transcribed to **active mRNA**. The other genes in that cell are not transcribed.

1. Particular genes are switched on in a developing cell.
 2. These genes are transcribed to produce mRNA, which is processed into active mRNA.
 3. The mRNA is translated at ribosomes to give specific proteins.
 4. The proteins control cell processes (as enzymes) or determine cell structure, so the cell takes on its particular shape and function.
- Animals: in developing red blood cells the haemoglobin genes are expressed, so the cells fill with haemoglobin; in beta cells of the pancreas the insulin gene is expressed; in muscle cells the genes for contractile proteins (actin, myosin) are expressed.
 - Plants: in cells of the leaf, genes for photosynthetic proteins are expressed, whereas in root hair cells they are not; in xylem cells, genes are expressed for the enzymes that make lignin, which thickens the wall.

This is how a stem cell becomes a specialised cell: a particular set of genes is switched on, and the proteins they code for control the cell's structure and function. It is also why a cell can contain a gene that it never expresses.



Every cell has the same genes; **only some are switched on** in each cell type.

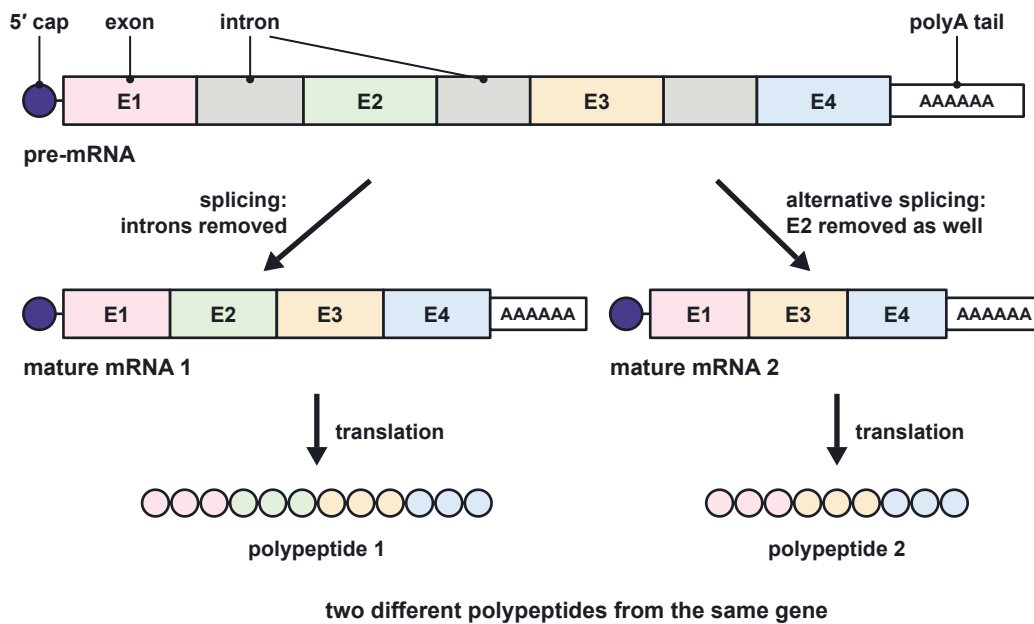
Common mistake: Specialised cells do not lose the other genes. They keep them all but do not transcribe them.

One gene, more than one protein Spec 3.19

The DNA of eukaryotic genes contains non-coding sections called **introns** between coding sections called **exons**. The whole gene is transcribed to give a primary transcript (pre-mRNA). Before it leaves the nucleus, it is changed. These are **post-transcriptional changes**.

1. The gene is transcribed to give pre-mRNA containing both exons and introns.
2. The introns are cut out and the exons are joined together. This is called **splicing**.
3. In alternative splicing, different combinations of exons are kept, or some exons are left out, so that different mature mRNA molecules are made from the same gene.
4. The mature mRNAs leave the nucleus through nuclear pores and are translated into different proteins (isoforms) with different amino acid sequences.

Alternative splicing means that the number of different proteins a cell can make is greater than the number of genes it contains. Different cell types may splice the same pre-mRNA in different ways, so the same gene can produce different forms of a protein in different tissues. Other changes to the pre-mRNA, such as adding a protective cap and a tail, also take place before the mRNA is used.



Alternative splicing: different combinations of exons give different proteins from one gene.

Exam tip: State that this is post-transcriptional (it happens after transcription, to the mRNA). Mutations change the DNA itself, so are different from splicing.

Genotype, environment and epigenetics Spec 3.20

The **phenotype** of an organism, its observable characteristics, is the result of an interaction between its **genotype** and the **environment**. Genes provide the potential, and the environment affects how it is expressed. Examples: height depends on genes and on nutrition; hydrangea flowers are pink or blue depending on the acidity of the soil; a plant grown in the dark has the genes for chlorophyll but is yellow; identical twins are genetically identical, but become different through different diets and lifestyles.

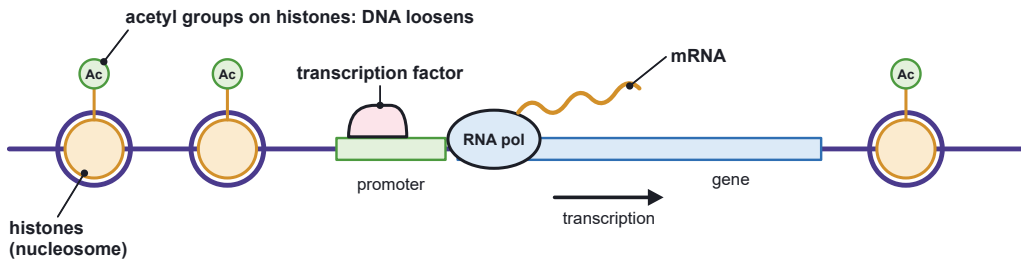
Epigenetic modification

Epigenetic modifications are chemical changes to DNA or to the histone proteins around which it is wound. They change whether a gene is **activated** (transcribed) without changing the sequence of bases.

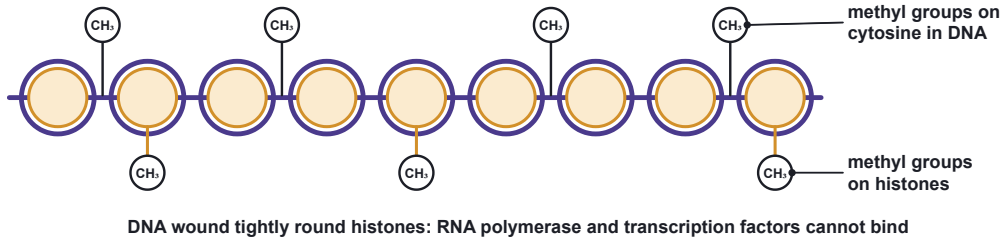
- **DNA methylation:** methyl groups (CH_3) are added to cytosine bases in DNA. This usually stops transcription factors and RNA polymerase binding, so the gene is switched off (silenced).
- **Histone modification:** chemical groups are added to or removed from histones. Acetylation loosens the DNA from the histones, so the gene can be transcribed (activated). Deacetylation (and some kinds of histone methylation) makes the DNA wind more tightly, so the gene is not transcribed (switched off). Histone methylation can activate or repress a gene depending on where the methyl group is added.

The environment (for example diet, stress or smoking) can change the pattern of epigenetic marks. The epigenetic changes **can be passed on following cell division**: after DNA is replicated, enzymes copy the methylation pattern onto the new strand, so daughter cells keep the same genes switched on or off. This is how a differentiated cell passes its pattern of gene expression on to its descendants.

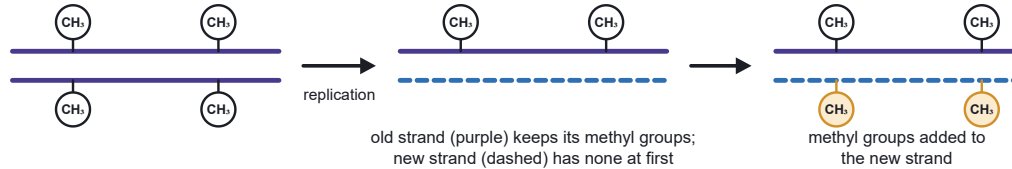
Gene switched ON: DNA loosely packed, gene transcribed



Gene switched OFF: DNA tightly packed, gene not transcribed



After DNA replication, enzymes copy the methyl groups onto the new strand



Acetylation loosens DNA and switches genes on; **methylation** packs it tightly and switches genes off.

Exam tip: Epigenetic modification does not change the base sequence of DNA. Say that it changes gene activity (transcription), and that this is different from a mutation.

Multiple alleles, polygenic inheritance and variation Spec 3.21

Multiple alleles

An individual has only two alleles of a gene, but a gene can have more than two alleles in a population. The ABO blood group is an example. The gene has three alleles: I^A , I^B and I^O . I^A and I^B are codominant, and both are dominant to I^O .

ABO blood groups	
Genotype	Phenotype (blood group)
$I^A I^A$ or $I^A I^O$	A
$I^B I^B$ or $I^B I^O$	B
$I^A I^B$	AB
$I^O I^O$	O

A genetic cross with multiple alleles

A man of blood group A (genotype $I^A I^O$) and a woman of blood group B (genotype $I^B I^O$) have a child. Give the possible blood groups of the child.

1. Gametes of the man: I^A or I^O . Gametes of the woman: I^B or I^O .
2. Possible genotypes: $I^A I^B$, $I^A I^O$, $I^B I^O$, $I^O I^O$, in the ratio 1 : 1 : 1 : 1.
3. The phenotypes are AB, A, B and O.

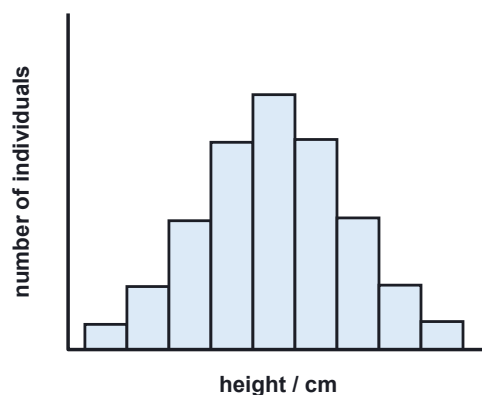
Answer: Any of the four groups A, B, AB or O, each with probability $\frac{1}{4}$

Polygenic inheritance and continuous variation

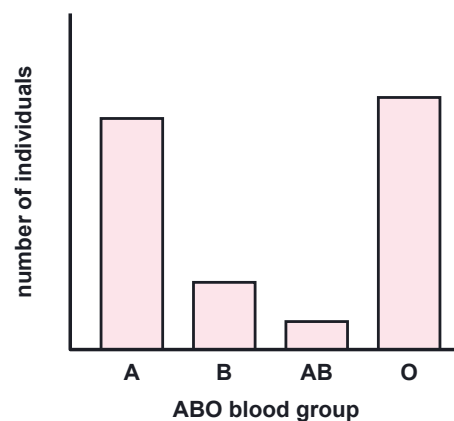
In **polygenic inheritance**, a characteristic is controlled by many genes at different loci, each contributing a small effect to the phenotype. These effects add together. Examples include human height and skin colour. The environment also affects the phenotype (for example, nutrition affects height). Together they give **continuous variation**: a range of phenotypes between two extremes, with no distinct categories. In a population the frequency distribution is usually a bell-shaped (normal) curve, and the characteristic is measured, not counted.

Discontinuous variation has distinct categories with no intermediates, such as ABO blood groups. It is controlled by one or a few genes and is little affected by the environment.

Maths skill: For continuous data, plot a histogram of the frequency table and find the mean (total $\div$ number), mode (most common value) and median (middle value when ranked). In a normal distribution these are about the same.



continuous variation
a range of phenotypes
between two extremes



discontinuous variation
a limited number of phenotypes
with no intermediates

Height shows **continuous variation** (polygenic, affected by the environment); blood group shows **discontinuous variation**.

Quick check

1. What is the difference between a totipotent cell and a pluripotent cell?
2. What is an exon?
3. How does DNA methylation affect gene expression?
4. Name the three alleles of the ABO blood group gene.
5. Why do cells with the same genes become different cell types?

Quick check answers

Cells, tissues and organelles

1. Any three of: cell surface membrane, cytoplasm, DNA (genetic material), ribosomes, enzyme-controlled metabolic reactions.
2. It makes ribosomal RNA and assembles ribosome subunits.
3. The Golgi apparatus.
4. It is circular, not associated with histones and not enclosed in a nucleus.
5. Oval shape, a double membrane and an inner membrane folded into cristae.

Microscopy and measuring cells

1. The smallest distance between two points at which they can still be seen as separate.
2. Electrons have a much shorter wavelength than light.
3. To increase contrast so that structures are visible and can be told apart.
4. Magnification = size of image $\div$ size of real object.
5. Its divisions have no fixed size; they depend on the objective lens, so they must be compared with a stage micrometer.

Chromosomes, meiosis and gametes

1. The location of a gene on a chromosome.
2. Prophase I.
3. To prevent other sperm from entering, which would cause polyspermy.
4. One fuses with the egg nucleus to form the zygote; the other fuses with the polar nuclei to form the endosperm.
5. To make ATP by aerobic respiration for the movement of the flagellum.

Mitosis and the cell cycle

1. The S phase of interphase.
2. They line up at the equator of the cell, attached to spindle fibres by their centromeres.
3. DNA is replicated exactly in interphase and each daughter cell receives one copy of every chromosome.
4. It contains meristem cells, which are dividing rapidly.
5. Number of cells in mitosis divided by the total number of cells observed.

Stem cells, gene expression and phenotype

1. A totipotent cell can form any cell type including placental cells; a pluripotent cell can form any body cell but not extra-embryonic tissue.
2. A coding section of a gene, which is kept in the mature mRNA.
3. It usually switches the gene off by preventing transcription.
4. I^A , I^B and I^O .
5. Different genes are expressed in each cell type, giving different active mRNA and proteins.